3. Pathogens and Nutrients

Department of Ecology, Environmental Assessment Program

OVERVIEW

The interaction of higher organisms with their environment involves the exchange of pathogens and nutrients between organisms and the environment. Pathogens consist of microorganisms (bacteria, protozoa and fungi) or viruses that cause disease. The monitoring of pathogens in the environment and the management of pathogenic waste streams from livestock, domestic animals and human wastewater are basic aspects of modern sanitation.

Where pathogens enter rivers and streams and drain to marine waters, they pose risks to humans through direct exposure or by entering the food stream supply through fish or shellfish. There is also an enormous economic incentive to maintain water quality because of the fisheries industries that rely on aquatic resources. This chapter addresses the monitoring of pathogens within the Puget Sound basin. The impacts of pathogens on human health are discussed in Chapter 5. Fecal coliform bacteria, a generally benign group of bacteria, are used as an indicator for the potential presence of pathogens that originate in the digestive tracts of warm-blooded animals. Major sources of fecal contamination include failed on-site septic systems, livestock grazing along streams, malfunctioning municipal sewage systems, boat waste and contaminated stormwater.

Nutrients are required by organisms for basic metabolic and growth processes. Two nutrients are discussed in this chapter: **nitrogen**—including ammonium—and **phosphorus**. Nutrient availability is frequently a limiting factor and therefore key to biological processes. Humans have massively altered the nitrogen cycle, in particular, through the capture of atmospheric nitrogen for the manufacture of fertilizers. The alteration of nutrient availability can have a major impact on ecosystems by improving conditions for some species to the detriment of others. In aquatic ecosystems an increase in nutrient availability—eutrophication—often provides favorable conditions for growth of macro-algae, phytoplankton and aquatic vegetation. The subsequent increase in organic matter leads to increased microbial decomposition and increased demand for oxygen. The resultant oxygen depletion can create a harmful environment for fish and other organisms.

This chapter discusses results from recent monitoring of pathogens and nutrients in fresh and marine waters. Some of the new findings and accomplishments that are highlighted in this chapter are summarized below.

Pathogens

- The Washington State Department of Ecology developed a new water quality index (WQI) to detect chronic problems with freshwater fecal coliform bacteria. The fecal WQI showed the lowest level of concern at most ambient freshwater stations within the Puget Sound basin for water year 2000 (24 of 33). No ambient monitoring stations were placed in the highest concern category (the remaining stations were in the moderate concern category).
- Trend analyses at 20 of the Department of Ecology's freshwater stations for 1991 through 2000 showed seven stations had decreasing fecal contamination. One station at Cedar Run in Renton had an increasing contamination and the remainder had no discernable trends.
- The Washington State Department of Health evaluated fecal pollution in 89 shellfish harvest areas for the period from March 2000 through March 2001. According to its Fecal Pollution Index, 29 areas had significant impact from fecal pollution. The following areas ranked highest in fecal impact: South Skagit Bay, Drayton Harbor, Chico Bay (Dyes Inlet) and Portage Bay. Sixty other harvest areas had minimal pollution.
- The state Department of Health analyzed five-year trends at 302 monitoring stations in Puget Sound that had sufficient data records and evidence of pollution. Fecal pollution increased significantly at 40 percent of the stations. Pollution decreased at one third of the sites and remained unchanged at 27 percent of stations.
- Results from 15 core marine water stations in Puget Sound monitored by the Department of Ecology in 2000 showed the lowest occurrence of high fecal coliform counts since 1994.
- In 2000, the Department of Ecology's ambient monitoring stations recorded the highest marine fecal coliform counts in Commencement, Elliott and Oakland bays. Oakland Bay, however, had only moderate fecal impact in statistics calculated by the state Department of Health using data from commercial shellfish growing areas.
- Subtidal marine water samples collected in central Puget Sound by King County in 1999 through 2000 all met national standards for fecal coliform except for two stations in Elliott Bay.
- Several years of analysis of water samples from King County beaches have shown several stations that:
    - Consistently have fecal coliform levels that exceed standards: Tramp Harbor, inner Elliott Bay, Fauntleroy Cove, Golden Gardens, Lake Washington Ship Canal and Piper's Creek.

  - Consistently have low fecal coliform levels: Seacrest Park, Duwamish Head, north side of Alki Point and Fay Bainbridge State Park.
  - Have highly variable results from year to year: Richmond Beach, Seahurst Park and southern West Point.
- A concerted multi-agency effort to control fecal coliform contamination from dairy farms and septic systems in the Whatcom County has led to dramatic improvements in contaminant levels in the Nooksack River.

Nutrients

- The Department of Ecology's WQI for total nitrogen indicated that the majority of ambient freshwater sampling stations (20 of 33 stations) were in the lowest concern category in wateryear 2000. The remaining stations were split between moderate concern (7) and highest concern (6). The highest concern stations were in the lower Skagit Valley and on the Deschutes River.
- The Department of Ecology's WQI for total phosphorus indicated three highest concern freshwater ambient monitoring stations—one in the Skagit Valley (Joe Leary Slough) and two in the lower Puyallup River drainage.
- A trend analysis of 1991 through 2000 data at the Department of Ecology's freshwater monitoring stations indicated decreasing trends or no trends for nitrogen throughout the Puget Sound basin. Slight increasing trends for phosphorus were identified at a number of stations.
- The Department of Ecology scientists identified three areas as having exceptional sensitivity to eutrophication due to a combination of low dissolved oxygen (DO), low dissolved inorganic nitrogen (DIN), and strong, persistent stratification in a 1994 through 2000 dataset. These areas are Budd Inlet, south Hood Canal and Penn Cove.

Findings on Pathogens

Rivers and Streams

As part of PSAMP, the Department of Ecology monitors ambient water quality parameters monthly at 33 river and stream sampling stations in the Puget Sound basin. The Department of Ecology recently started reporting freshwater conditions using a WQI for eight individual parameters in addition to a single overall WQI for each sampling station (Ecology 2001; see Chapter 2). The WQI is designed to detect chronic water quality problems rather than isolated spikes in conditions. Fecal coliform concentration is one of the parameters analyzed with an individual WQI (Butkus et al. 2001). While fecal coliform bacteria are not pathogens themselves, they are used as indicators of the presence of pathogens.

Figure 3-1 shows the fecal coliform WQI at the ambient sampling stations for wateryear 2000, the latest year available. The majority of the stations had fecal coliform conditions in the lowest concern category (24 of 33 stations). The other stations were placed in the moderate concern category. There were no ambient monitoring stations in the highest concern category for fecal coliform contamination. Department of Ecology scientists performed trend analyses on data from 20 of these ambient monitoring stations using data spanning 1991 to 2000.

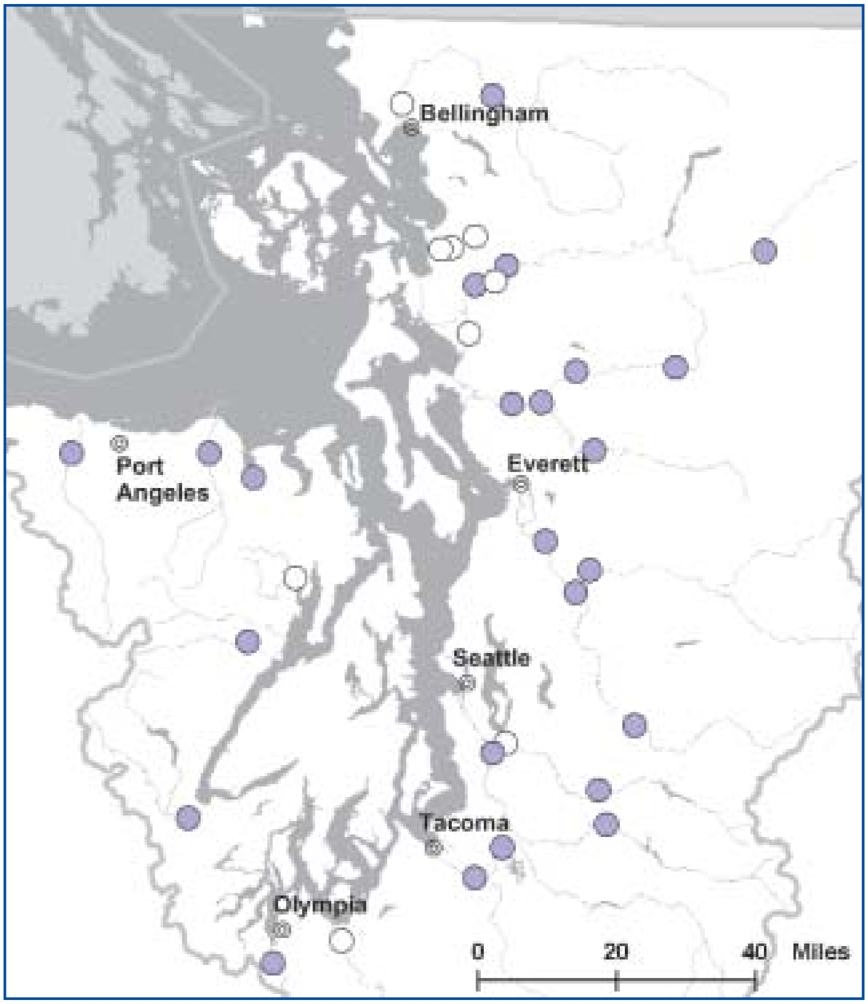


Figure 3-1. Fecal coliform conditions in rivers and streams as measured by the Department of Ecology's fecal coliform Water Quality Index (WQI) for wateryear 2000.

- Highest Concern
- Moderate Concern
- Lowest Concern

Source: Washington State Department of Ecology

Most stations had no significant trend, but seven had decreasing trends in fecal coliform concentrations and one had an increasing trend. The seven stations with decreasing trends are: Nooksack River at Brennan; Stillaguamish River near Silvana; South Fork Stillaguamish at Arlington; North Fork Stillaguamish at Cicero; Snohomish River at Snohomish; Green River at Tukwila; and Puyallup River in Puyallup. The single increasing trend was seen in the Cedar River station at Renton.

Controlling Fecal Coliform Contamination in the Nooksack Watershed

Whatcom County has the most dairies in the state. Poor manure management practices used by Whatcom County dairy farmers in the early 1990s contributed the largest loading of bacterial pollution to the Nooksack River, resulting in the closure of the Portage Bay shellfish beds and declining water quality throughout the county. Since 1998, however, dairy farmers have worked with federal, state and local agencies to improve water quality in many Whatcom County streams.

Whatcom County Conservation District and Natural Resources Conservation Service staff have provided technical assistance to many dairy farmers and have developed 150 dairy nutrient management plans. These plans provide farmers with specific practices to control manure from entering streams. Two Department of Ecology inspectors have completed 600 dairy inspections in Whatcom County and have issued 36 enforcement actions to stop or correct discharges of manure into streams. Whatcom County Health and Planning departments have, respectively, repaired failing septic

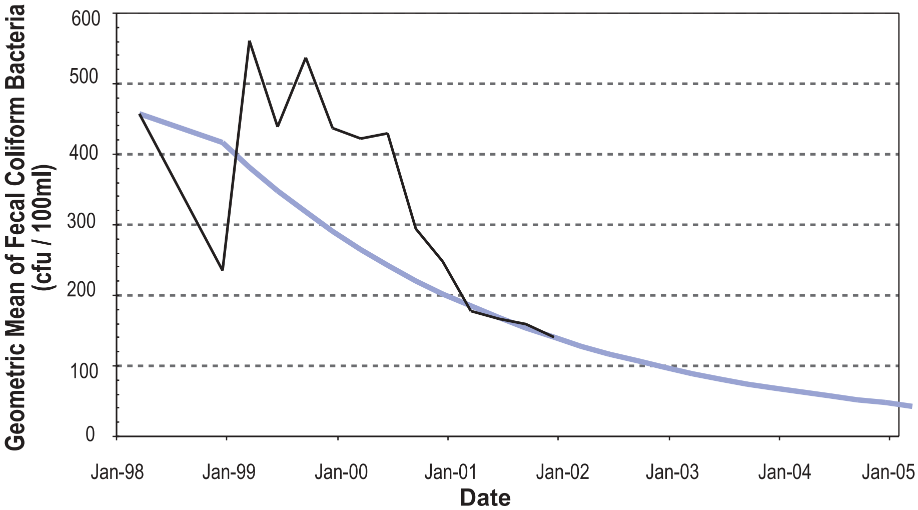


Figure 3-2. Observed and target fecal coliform levels (geometric mean) called for in the Total Maximum Daily Load (TMDL) cleanup plan for Fishtrap Creek in the Nooksack watershed. Similar patterns have been documented elsewhere in the Nooksack watershed.

Target

Observed

Source: Washington State Department of Ecology

systems or issued enforcement actions to remove animals from entering streams. Many farmers have changed their farm practices voluntarily to meet the goal of keeping streams clean. Some have even installed tree and shrub buffers along streams flowing through their farm property.

Water quality monitoring since 1998 by the Northwest Indian College has measured the results of these individual efforts. Data for the 2001 year show fecal coliform bacteria levels in the Nooksack River and in Portage Bay are substantially improved from 1997 through 1998 levels (Figure 3-2).

Fecal Contamination in Commercial Shellfish Growing Waters

The state Department of Health classifies commercial shellfish beds according the guidelines set by the U.S. Food and Drug Administration's National Shellfish Sanitation Program (NSSP) based largely on sampling of fecal coliform bacteria in marine waters in shellfish growing areas. As of May 2001, the state Department of Health has classified nearly 200,000 acres in nearly 100 growing areas statewide as Approved or Conditionally Approved for shellfish harvest. In the 1980s the state Department of Health downgraded almost 33,000 acres; only 1,000 acres were upgraded. However, in the 1990s, upgraded acreage nearly equaled downgraded acreage.

The PSAMP analysis of state Department of Health data addresses two broad questions:

- What is the status of fecal coliform contamination relative to Department of Health's growing area standards?
- Has fecal pollution changed significantly over time?

State Department of Health scientists calculated growing area statistics (geometric means and ninetieth percentiles) for more than 1,114 stations in 89 shellfish growing areas using monitoring data collected through March 2001.

Growing Area Status

The status of each growing area was determined for the period from March 2000 through March 2001. Each station within a growing area was categorized according to the highest 90th percentile occurring at the sampling station during the period:

Water Quality Index and the 303(d) List

The results from The Department of Ecology's Water Quality Index (WQI) analysis for fecal coliform shows a different picture than the contents of the most recent 303(d) list (1998) for impairment due to fecal coliform contamination. The two approaches involve different data sources as well as different analyses. The WQI is based on data from ambient monitoring stations that are selected to represent overall watershed conditions. The WQI analysis itself is designed to detect chronic water quality problems rather than short-term spikes in contaminants. In contrast, the 303(d) list is based on data from multiple sources that focuses on localized water quality problems and includes cases where contaminants appear only briefly in addition to cases with chronic impairment.

Most Probable Number and Colony Forming Units

Concentrations of fecal coliform bacteria are reported either in units of Most Probable Number (MPN) or Colony Forming Units (cfu). These units are generally considered to be equivalent, but they indicate which of two different techniques was used to measure the concentration. Values reported in cfu are derived from counting the number of colonies grown in a culture. Values reported in MPN are derived from the measurement of carbon dioxide given off by cultured colonies.

GOOD (0-30 MPN per 100 ml)

FAIR (31-43 MPN per 100 ml)

BAD (above 43 MPN per 100 ml)

The fraction of sampling stations within each category was used to produce a pie chart for each growing area. These pie charts provide a means to visually compare 89 growing areas in Puget Sound and the straits of Georgia and Juan de Fuca (Figure 3-3). South Skagit Bay, Drayton Harbor, and Chico Bay (Dyes Inlet) appear to be the most affected by fecal pollution.

Ranking of Fecal Impact in Growing Areas and Regions

Each growing area was ranked according to fecal pollution impact by calculating a "Fecal Pollution Index" or FPI. First, the fraction of stations within each category was multiplied by a corresponding weighting factor (good: 1.0; fair: 2.0; or bad: 3.0). Next, the resulting weighted fractional values are added to produce the FPI. If all stations in the growing area are good, the index is 1.0 (1.00 x 1.0). On the other hand an index of 3.0 means all stations are bad (1.00 x 3.0). A growing area with a mixture of categories would fall between the extremes. Figure 3-4 shows the indices of 29 growing areas (one third of the total) with values greater than 1.0. The data in Figure 3-4 confirms our visual impressions from Figure 3-3. South Skagit Bay has been affected the most (FPI = 2.8), followed by Drayton Harbor (FPI = 2.6) and Chico Bay (FPI = 2.3).

The concept of calculating FPI was extended to the level of the region. The 89 growing areas are divided into six regions:

1. North Puget Sound and Georgia Strait (areas 1-17)
2. Admiralty Inlet and the Puget Sound Main Basin (areas 18-31)
3. South Puget Sound (areas 32-61)
4. San Juan Islands (areas 62-67)
5. Strait of Juan de Fuca (areas 68-76)
6. Hood Canal (areas 77-89)

For each region the total number of stations within each category (good, fair, bad) was calculated. Next, the count of stations in each category was weighted by a value of 1.0, 2.0 or 3.0 as described above. The weighted proportions were summed to produce an FPI for each of the regions: The FPI for North Puget Sound/Georgia Strait was nearly identical to that of South Puget Sound (FPI =1.28 and 1.25, respectively). Next in order came the Strait of Juan de Fuca (FPI = 1.12), Admiralty Inlet and the Main Basin (FPI =1.08), Hood Canal (FPI = 1.06), and the San Juan Islands (FPI = 1.0).

Trends in Fecal Coliform Contamination

The period of record for many growing areas extends back for over a decade. However, the time period for this year's PSAMP trends analysis was limited to a maximum of five years prior to March 2001 to detect recent changes. Trends in 90th percentiles were analyzed for stations that had: (1) 90th percentiles greater than 10 MPN per 100 ml, or (2) a length of record longer than three years. The 302 "trend" stations (27 percent of total stations) were located in nearly half of the 89 growing areas discussed above. About 40 percent of the trend stations showed significant worsening conditions. One-third showed improving conditions, and the remaining 27 percent had not changed significantly.

Scientists at the state Department of Health have also assessed trends in fecal contamination by examining the number of sampling stations within each shellfish growing area that have increasing contamination. Henderson Inlet in south Puget Sound had the largest fraction of worsening stations (15 of 26 stations). Other areas

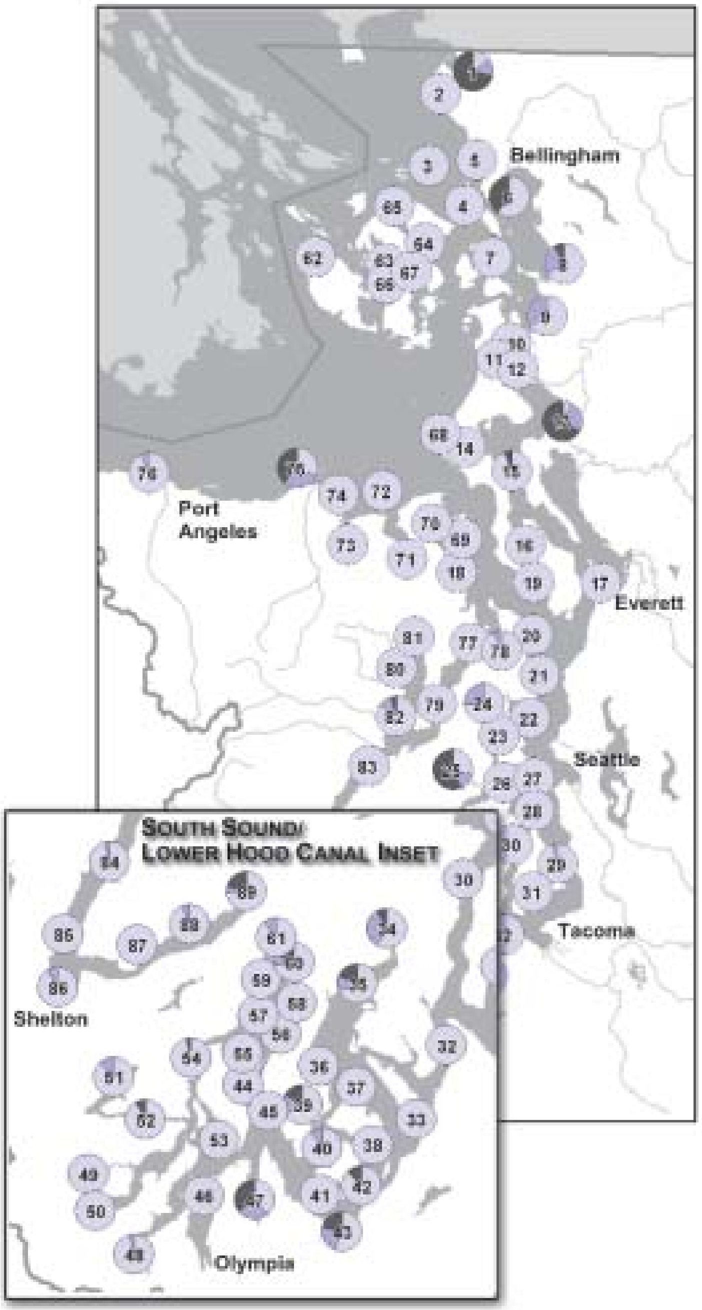


Figure 3-3. Fecal pollution of shellfish beds in Puget Sound and the straits of Georgia and Juan de Fuca, 2000.

Pie charts show proportion of sampling stations in three categories based on 90th percentiles. Based on data from January 2000 through March 2001.

Good: Statistic <=30 MPN/100 ml

Fair: Statistic >30 MPN/100 ml, but <= 43 MPN/100ml

Bad: Statistic > 43 MPN/100 ml

Source: Washington State Department of Health

▶ (Growing areas listed in **BOLD** have stations that are categorized as FAIR or BAD.)

NORTH PUGET SOUND AND GEORGIA STRAIT

1. Drayton Harbor
2. Birch Bay
3. Alden Banks
4. Lummi Island
5. Lummi Bay
6. Portage Bay
7. East San Juan Islands
8. Samish Bay
9. Padilla Bay
10. Similk Bay
11. North Whidbey Island
12. Swinomish
13. South Skagit Bay
14. Penn Cove
15. Saratoga Passage
16. Holmes Harbor
17. Possession Sound

ADMIRALTY INLET AND MAIN BASIN PUGET SOUND

18. Oak Bay
19. SW Whidbey Island
20. Eglon
21. Kingston
22. Port Madison
23. Agate Passage
24. Lemolo (Liberty Bay)
25. Chico Bay (Dyes Inlet)
26. Port Orchard Passage
27. Port Blakely
28. Blake Island
29. East Passage
30. Colvos Passage
31. Quartermaster Harbor

SOUTH PUGET SOUND

32. Tacoma Narrows
33. Fox Island
34. Burley Lagoon
35. Henderson Bay
36. Penrose Point SP
37. Wyckoff Shoals
38. Balch Passage
39. Filucy Bay
40. Drayton Passage
41. Thompson Cove
42. Oro Bay (Anderson Island)
43. Nisqually Reach
44. McMicken Island
45. Whiteman Cove
46. Budd Inlet
47. Henderson Inlet
48. Eld Inlet
49. Skookum Inlet
50. Totten Inlet
51. Oakland Bay
52. Hammersley Inlet
53. Peale Passage
54. Pickering Passage
55. Spencer Cove
56. Dutcher Cove
57. Stretch Island
58. Vaughn Bay
59. Reach Island
60. Rocky Bay
61. North Bay

SAN JUAN ISLANDS

62. Westcott Bay
63. Blind Bay
64. Buck Bay
65. East Sound
66. Upright Channel
67. Shoal Bay

STRAIT OF JUAN DE FUCA

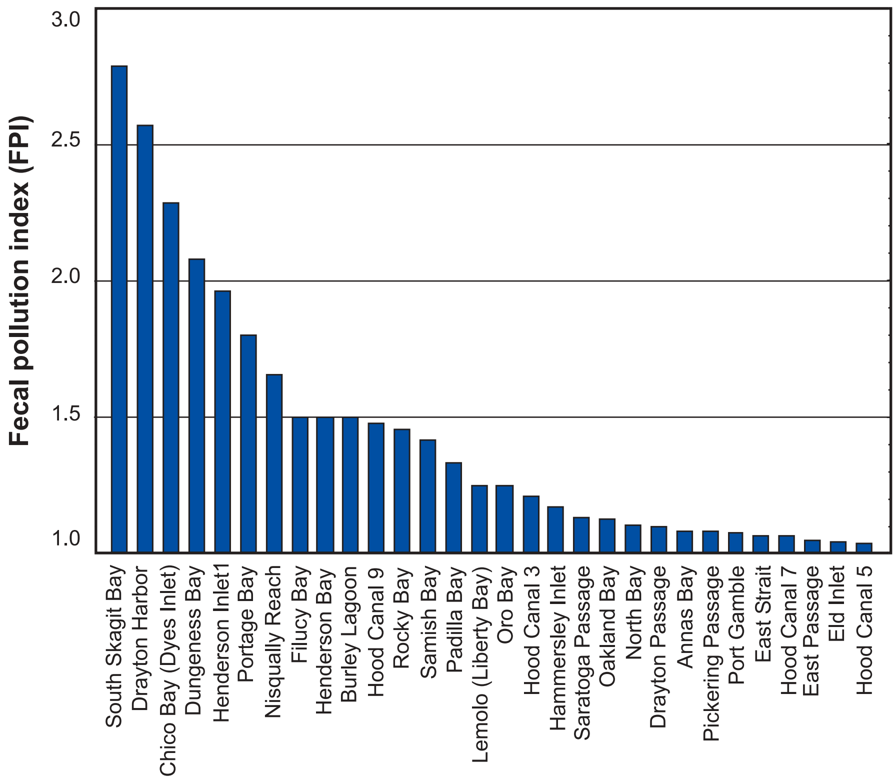
68. Pt. Partridge
69. Kilisut Harbor/ Mystery Bay
70. Port Townsend
71. Discovery Bay
72. Protection Island
73. Sequim Bay
74. Jamestown
75. Dungeness Bay
76. East Strait

HOOD CANAL AND APPROACHES

77. Hood Canal #1
78. Port Gamble
79. Hood Canal #2
80. Quilcene Bay
81. Dabob Bay
82. Hood Canal #3 (incl. Dosewallips)
83. Hood Canal #4
84. Hood Canal #5 (incl. Lilliwaup)
85. Hood Canal #6
86. Annas Bay
87. Hood Canal #7
88. Hood Canal #8
89. Hood Canal #9 (Lynch Cove)

Figure 3-4. Shellfish growing areas ranked by fecal coliform impact.

Source: Washington State Department of Health



with noteworthy worsening trends included South Skagit Bay in North Puget Sound (9 of 14 worsening stations) and Dungeness Bay on the Strait of Juan de Fuca (11 of 13 worsening stations). Generalized worsening trends might seem to be a feature of heavily impacted areas, but this isn't always the case. Buck Bay in the San Juan Islands (4 worsening stations out of 5) and Port Blakely on Bainbridge Island (6 of 8 stations getting worse) are currently good (i.e., FPI=1.0). However, their overall worsening trends suggest vigilance is in order.

Sources of Fecal Pollution

Table 3-1 summarizes fecal pollution sources that were historically identified for some growing areas selected from Figure 3-4. Actions have been taken to minimize the impacts of many of these sources. The sources of fecal pollution emanating from rural watersheds have tended to be similar regardless of their location in Western Washington. Major sources contributing to most growing areas are livestock grazing along streams and drainages, and failed on-site sewage systems along the marine shoreline. In Oakland Bay, Henderson Inlet and Drayton Harbor, sewage and contaminated stormwater from towns were important sources. Boat waste and marine wildlife have generally been shown to be seasonal, or highly localized in their effect.

Remedial Action

Local governments and citizens have conducted remedial action programs in most Puget Sound watersheds for more than a decade. The degree of effort has varied among programs, and outcomes have been mixed. An intensive program conducted by the Thurston County Health Department in the mid-1990s in Eld Inlet focused on locating and repairing on-site sewage systems. The effort significantly reduced fecal pollution and allowed the state Department of Health to upgrade the growing area. Likewise, fecal pollution in Oakland Bay was significantly reduced during a decade-long program by the City of Shelton to upgrade and repair its municipal sewage system. On the other hand, major efforts to eliminate raw sewage discharges in Bow, Edison and Blanchard have not yet significantly reduced fecal pollution loading into Samish Bay, possibly because reductions in fecal coliform from these discharges were overshadowed by inputs from the extensive pasture lands on the Samish River floodplain.

Fecal Contamination at Offshore and Nearshore Areas of King County

King County monitored bacteria (fecal coliform and *Enterococcus*) at 21 and 29 beach stations and 14 and 17 subtidal stations in 1999 and 2000, respectively. *E. coli* was also monitored at 8 subtidal stations in 1999 and at 8 subtidal and 14 beach stations in 2000 (Figure 3-5).

Water Column

All water column stations (including those near wastewater treatment plant discharges) met Class AA fecal coliform surface water standards in both 1999 and 2000 with the exception of two stations located in inner Elliott Bay. Fecal coliform

Map#	Growing Area	FPI	Description of historical fecal sources. (Note: Remedial action is underway in all growing areas.)
13	South Skagit Bay	2.79	1. Livestock herds in Skagit River delta. 2. On-site sewage from failed sewage systems in uplands and along marine shorelines. 3. Sewage treatment plants and stormwater from nearby towns. 4. Food processor discharges in nearby towns. 5. Seasonally migrating birds in lowland pastures
1	Drayton Harbor	2.57	1. Livestock along upland streams. 2. Bypasses and leaks in Blaine sewer system. 3. Contaminated stormwater runoff from streets, roads. 4. Boat waste from two marinas. 5. Waste discharge from fish canneries. 6. Marine mammals and birds
75	Dungeness Bay	2.00	1. Livestock along upland streams. 2. On-site sewage systems along marine shorelines and along upland streams. 3. Marine mammals and migrating birds.
47	Henderson Inlet	1.96	1. Livestock along upland streams. 2. On-site sewage systems along marine shorelines and along upland streams. 3. Contaminated stormwater runoff from streets, roads. 4. Marine mammals.
6	Portage Bay	1.80	1. Dairy herds along the Nooksack River. 2. Contaminated stormwater runoff from streets, roads. 3. Marine mammals.
34	Burley Lagoon	1.50	1. Livestock along upland streams. 2. On-site sewage systems along marine shorelines and upland streams.
8	Samish Bay	1.42	1. Livestock herds along lower Samish River. 2. Direct sewage discharge from Bow, Edison villages. 3. On-site sewage systems in Blanchard and along marine shorelines. 4. Seasonally migrating birds in lowland pastures.
51	Oakland Bay	1.13	1. Bypasses and leaks in Shelton sewer system. 2. Livestock along upland streams. 3. On-site sewage systems along marine shorelines.
48	Eld Inlet	1.04	1. On-site sewage systems along marine shorelines. 2. Livestock along upland streams.

Table 3-1. Sources of fecal pollution affecting selected shellfish growing areas in Puget Sound and the straits of Georgia and Juan de Fuca.

For each growing area the Fecal Pollution Index (FPI) and the area number corresponding to Figure 3-3 are shown.

Source: Washington State Department of Health

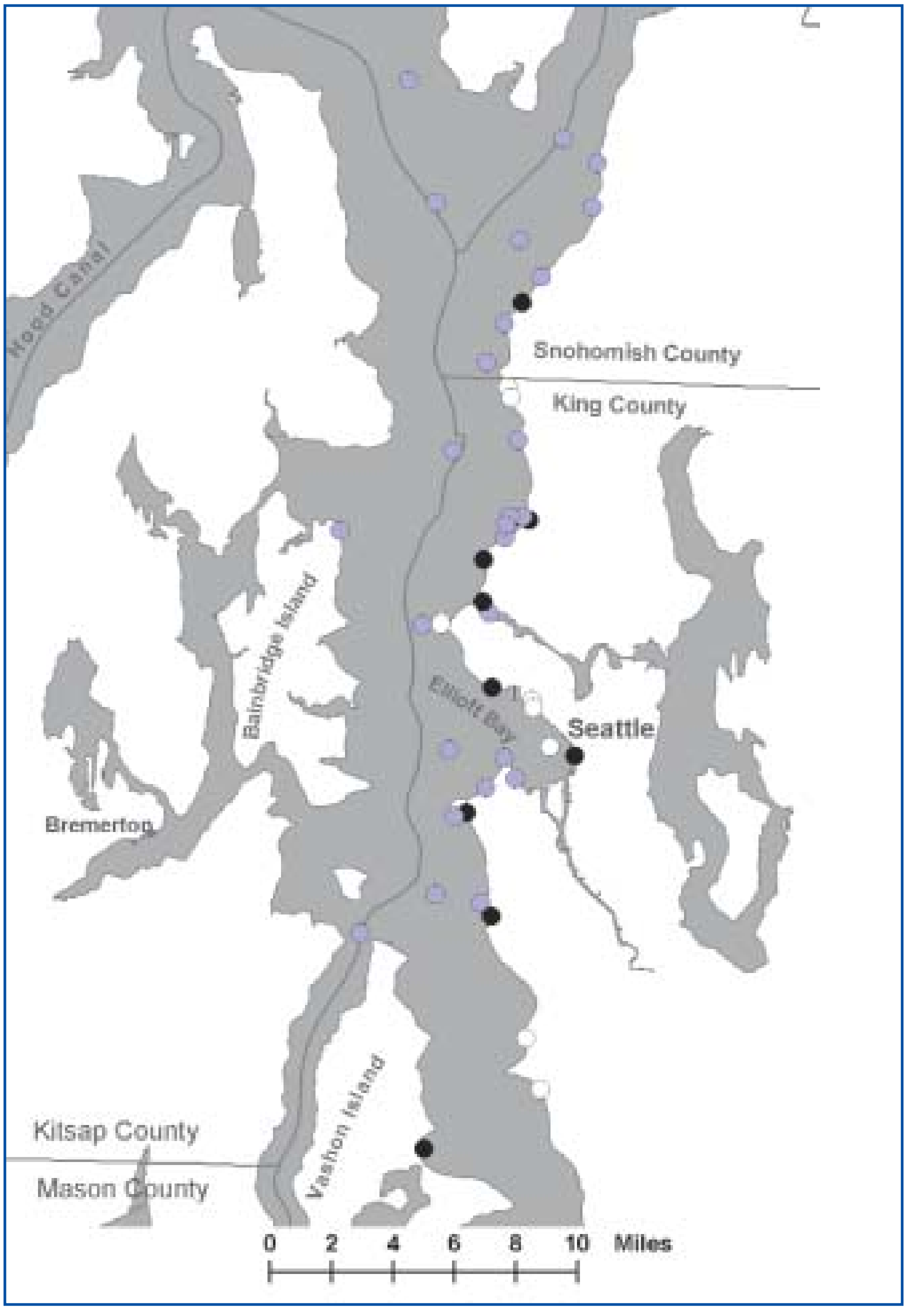
Figure 3-5. King County bacteria sampling stations.

Passed both standards

Variable results

Exceeded both standards

Source: King County Department of Natural Resources and Parks



counts at these stations have met the geometric mean but exceeded the peak standard for the past several years. Both these stations receive higher freshwater input than other water column stations sampled due to their proximity to the Duwamish River and exceedences of the peak standard occurred most frequently when rain fell prior to sampling.

As with fecal coliform bacteria, *Enterococcus* bacteria in water column samples were low, if detected at all, in both 1999 and 2000. There was no spatial trend detected and levels at the treatment plants outfalls were similar to ambient stations.

E. coli was monitored at eight subtidal stations in 1999 and 2000. As with both fecal coliform and *Enterococcus* bacteria, *E. coli* levels in subtidal waters were detected at low levels, if at all. Of all the samples analyzed, 94 percent were at or below one colony forming unit per 100ml (cfu/100ml).

Beaches

Fecal coliform concentrations in water samples from beaches can be influenced by freshwater runoff and waterfowl congregating in these areas. As a result, the number of stations exceeding standards increased during high rainfall months and at stations close to streams and other sources of freshwater runoff. Stations in areas with restricted water movement tend to retain freshwater input for a longer period of time and also frequently exceed standards. Stations in Tramp Harbor, inner Elliott Bay, Fauntleroy Cove; Golden Gardens, near the Lake Washington Ship Canal; and Piper's Creek have consistently failed both the geometric and peak standards for the last five years. Although sampling has been limited (less than two years of data) at a station located at Brackett's Landing in Edmonds, 11 of 19 samples had fecal coliform values over 43 cfu/100 ml.

In contrast to the above-mentioned beaches, stations near Seacrest Park, Duwamish Head, the north side of Alki Point, and the exposed beach at Fay Bainbridge State Park have consistently had low bacteria concentrations over the past several years and have met both water quality standards. Some stations, including Richmond Beach, Seahurst Park, and the southern West Point station, have variable results from year to year and do not show a consistent pattern.

Enterococcus bacteria counts at beach stations varied from station to station and from month to month. Values tended to be higher in the higher rainfall months for both years, but did not show a consistent pattern with rainfall. Generally, *Enterococcus* bacteria counts were not elevated when fecal coliform results were high and overall did not correspond with fecal coliform results.

E. coli was monitored at 14 beach stations in 2000. *E. coli* values for beach stations varied with month and station with the highest proportion of values between 10 to 50 cfu/100 ml. Boeing Creek, Meadowdale Beach Park, and the Carkeek stations had the lowest *E. coli* counts throughout the year. As with fecal coliform bacteria, the Brackett's Landing station had the highest *E. coli* values throughout the year with counts ranging from 3 to 920 cfu/100 ml. Bacteria concentrations at this station were not associated with rainfall.

While *Enterococcus* and fecal coliform bacteria values do not appear to be related, *E. coli* and fecal coliform bacteria for the beach stations sampled in 2000 do show a similarity when sampled concurrently. Figure 3-6 shows the fecal coliform, *Enterococcus*, and *E. coli* bacteria levels measured at the Brackett's Landing station.

Department of Ecology Monitoring of Open Marine Waters

Department of Ecology scientists analyzed marine water at 45 stations in Puget Sound for fecal coliform bacteria in 1998 through 2000. Results for 15 core stations that have been sampled monthly since 1992 are shown in Figure 3-7. Fecal coliform results are shown separated into two groups: those that exceed 14 colony forming units per 100ml (cfu/100ml) and those that exceed 43 cfu/100ml. These thresholds are state standards when applied to geometric mean values. In this analysis, the Department of Ecology uses this threshold to categorize stations based on individual samples. The results from these 15 core stations show a decrease in the 14 to 43 cfu/100ml group in 1999 relative to the previous year and a decrease in both categories in 2000. Results from 2000 reflected the second lowest frequency of high fecal counts in this data record, after 1994. These results reflect changes in the sources of fecal coliform contamination as well as transport of the contamination throughout the basin to the marine waters in Puget Sound. Both 1999 and especially 2000 were years of below-average rainfall which may be at least partially explain the decreasing trend over these two years.

Pathogen Indicators

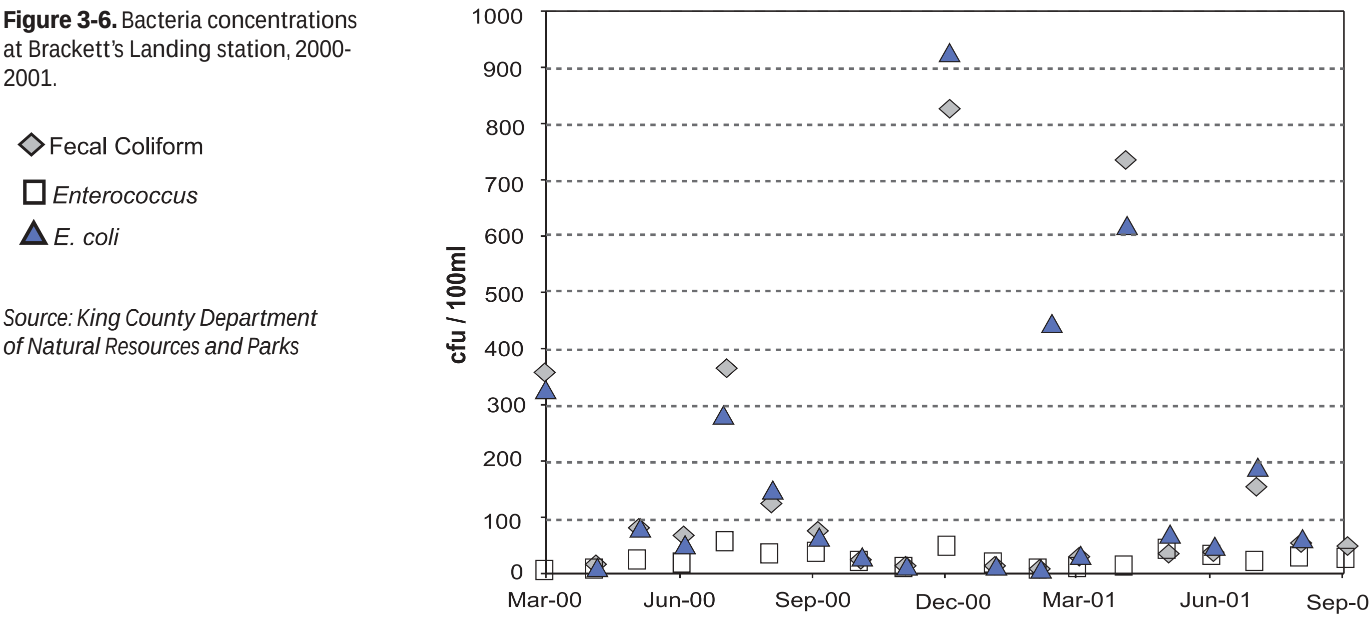
Fecal coliform, *E. coli* and *Enterococcus* are all bacteria used to test for the likely presence of other pathogens. Fecal coliform refers to a sub-group of bacteria in the coliform group that is a normally in the intestines of warm-blooded animals. *E. coli* is one species of bacteria in the fecal coliform group. The presence of *E. coli* has been shown to be better correlated with the occurrence of swimming-related illnesses than the test for more general fecal coliform bacteria. *Enterococcus* is a group of bacteria unrelated to the coliforms that also lives in the intestines of warm-blooded animals. This group is also more highly correlated with swimming-related illnesses than is fecal coliform.

Marine Fecal Coliform Standards

Washington State marine Class AA fecal coliform standards for surface waters state that organism counts shall not exceed a geometric mean value of 14 colony forming units per 100 ml (cfu/100ml) and not more than 10 percent of the samples used to calculate the geometric mean may exceed 43 cfu/100 ml. King County and the state Department of Health use results from the 30 most recent samples (surface samples only) to obtain geometric mean values as per the guidelines in the National Shellfish Sanitation Program (NSSP 1999). Surface samples are used, as these tend to be the highest values and represent the area where most contact occurs with people and intertidal organisms. The Department of Ecology uses these numeric thresholds somewhat differently by comparing individual measurements rather than the geometric mean.

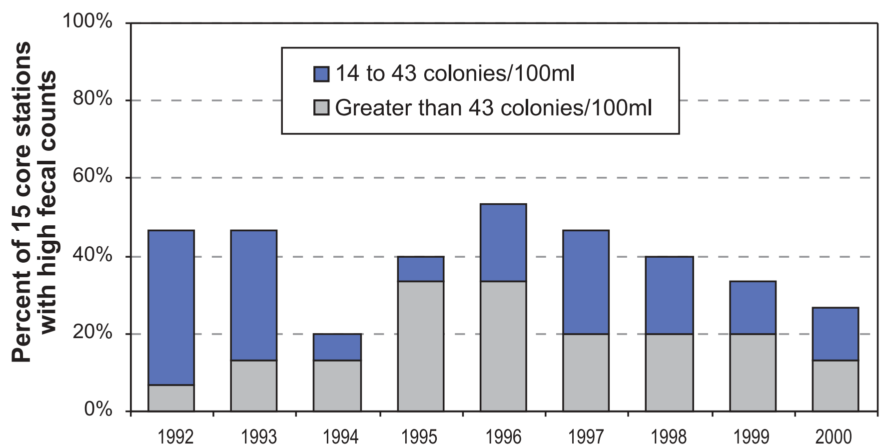
The NSSP guidelines are also discussed in Chapter 5, "Human Health."

Figure 3-6. Bacteria concentrations at Brackett's Landing station, 2000-2001.



Source: King County Department of Natural Resources and Parks

Figure 3-7. Puget Sound marine monitoring stations in two categories based on maximum observed fecal coliform contamination.



Source: Washington State Department of Ecology

Results from all 45 stations sampled in 1998 through 2000 are shown in Figure 3-8 and are grouped into low, moderate and high concentration categories. These categories are delineated using the same thresholds as above, i.e. 14 cfu/100ml and 43 cfu/100ml. The highest fecal contamination is seen in Commencement Bay, Elliott Bay, and Oakland Bay. High levels of contamination were also seen on the outer coast. This result for Oakland Bay contrasts with the results of the state Department of Health analysis where Oakland Bay has only modest contamination (see Figure 3-4). This difference is likely due to the location of the ambient station used by the Department of Ecology relative to the area of the shellfish growing area used by Department of Health as well as differences in the analysis of the data. The Department of Ecology identifies high fecal concentrations in individual monthly samples while the state Department of Health analysis is based on the geometric mean of 30 samples.

Findings on Nutrients

Rivers and Streams

As part of PSAMP, the Department of Ecology monitors water quality parameters monthly at 33 river and stream sampling stations in the Puget Sound basin. The

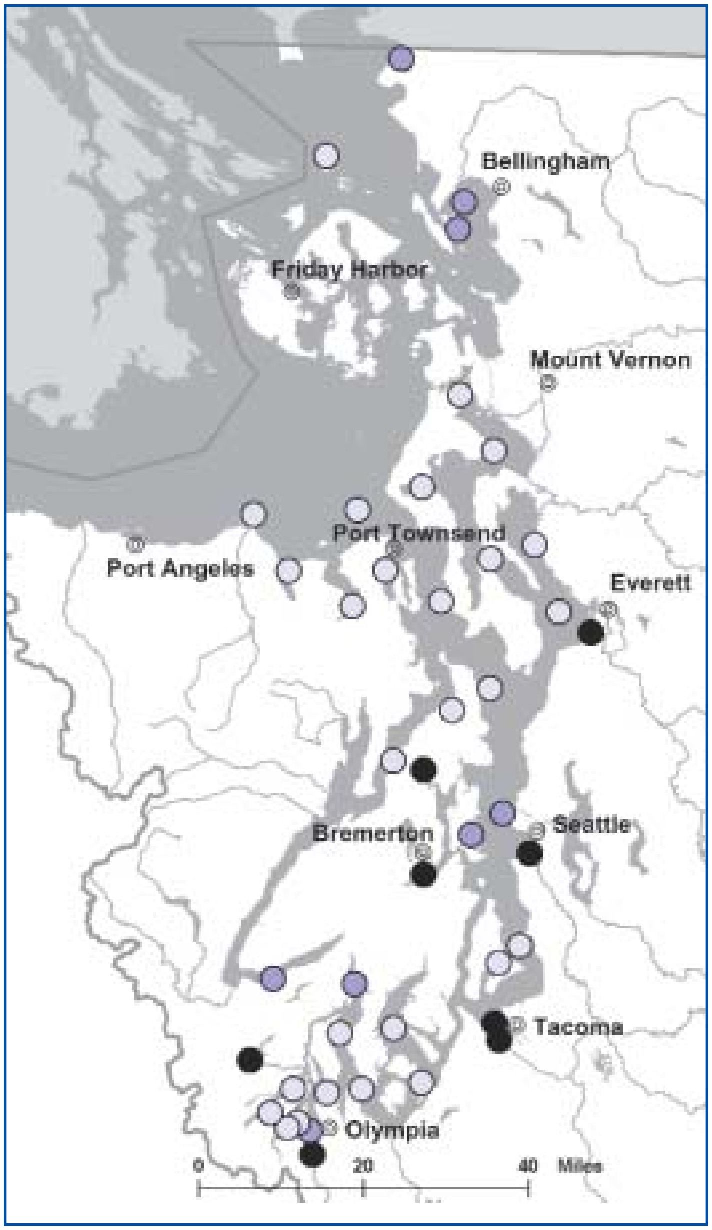


Figure 3-8. Distribution of maximum-observed fecal contamination at the Department of Ecology's open water monitoring stations in Puget Sound, 1998-2000.

High (>43cfu/100ml)
Moderate (14-43cfu/100ml)
Low (<14cfu/100ml)

Source: Washington State Department of Ecology

Department of Ecology recently started reporting freshwater conditions using a water quality index (WQI) for eight individual parameters in addition to a single overall WQI for each sampling station (Ecology 2001; see also Chapter 2). Two of these parameters assess the nutrient status of rivers and streams and are based on measured total concentrations of nitrogen and phosphorus (Butkus et al. 2001). When concentrations of nitrogen and phosphorus are elevated significantly over background levels this may indicate the presence of some pollutant source. A common source is runoff from agricultural or residential areas where fertilizers are used.

Figure 3-9 shows the total nitrogen WQI for the 33 sampling stations within the Puget Sound basin. The results indicate good conditions with respect to nitrogen for the majority of the stations (20 out of 33 stations). The remaining stations are almost equally split between the fair (7 stations) and poor (6 stations) classes. The poor stations are clustered in the lower Skagit valley but include a station on the Deschutes River in the southern area of the basin.

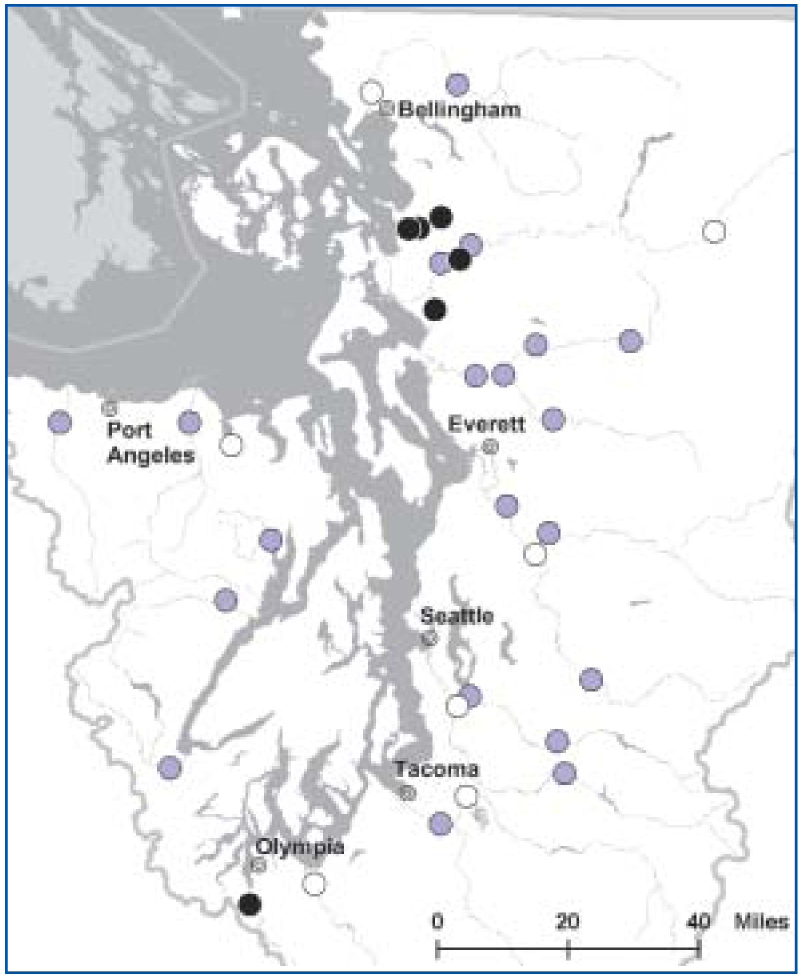


Figure 3-9. Total nitrogen conditions in rivers and streams as measured by the Department of Ecology's total nitrogen water quality index (WQI) for wateryear 2000.

- Highest Concern
- Moderate Concern
- Lowest Concern

Source: Washington State Department of Ecology

The total phosphorus WQI (Figure 3-10) shows a different pattern than the nitrogen WQI (Figure 3-9). Only three stations were rated poor with the others equally split between good and fair (15 stations each). The stations rated poor include Joe Leary Slough in the Skagit Valley, and two stations in the lower Puyallup River drainage.

Department of Ecology scientists performed a trend analysis on 20 of the 33 stations within the Puget Sound basin using data spanning 1991 to 2000. In the case of total nitrogen, they found that data from most of these stations had no significant trend; but in three cases, scientists detected downward trends in total nitrogen concentration. These three stations are: Snoqualmie River near Monroe; Nisqually River near Nisqually; and Skokomish River near Potlatch.

In contrast, Department of Ecology scientists found increasing trends in total phosphorus concentrations at five monitoring stations during the 1991 to 2000 data record. Data from the other 15 stations showed no significant trend. The five stations with increasing trends are: Cedar River near Landsburg; Green River at Kanaskat; Nisqually River at Nisqually; Deschutes River at Tumwater; and Skokomish River near Potlatch.

Marine Waters

Nutrient concentrations in Puget Sound marine waters are the result of a balance of inputs from rivers, streams, and the Pacific Ocean and removal of nutrients by

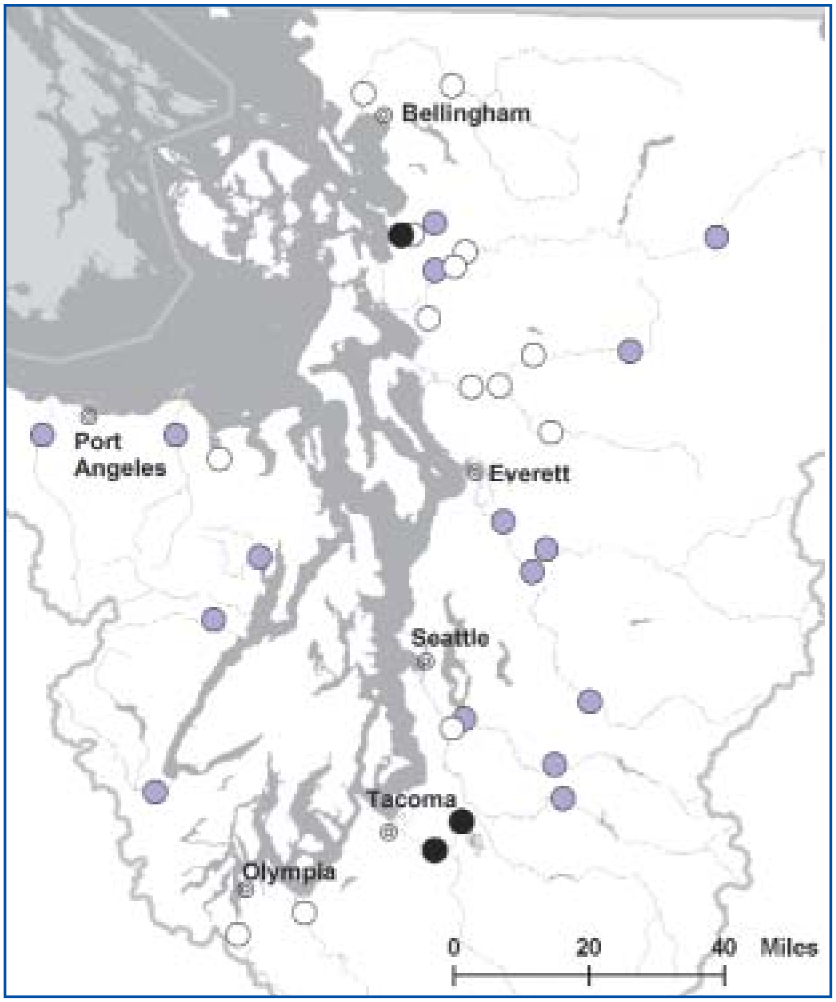


Figure 3-10. Total phosphorus conditions in rivers and streams as measured by the Department of Ecology's total phosphorus WQI for wateryear 2000.

Source: Washington State Department of Ecology

phytoplankton and aquatic vegetation. Scientists from the Department of Ecology analyze marine water samples for dissolved inorganic nitrogen (DIN) and ammonium. Results summarized for 1998 through 2000 are shown in Figure 3-11 (DIN) and Figure 3-12 (ammonium). These parameters were also used to determine an overall marine water quality concern index that also incorporated physical and pathogen parameters (see Chapter 2).

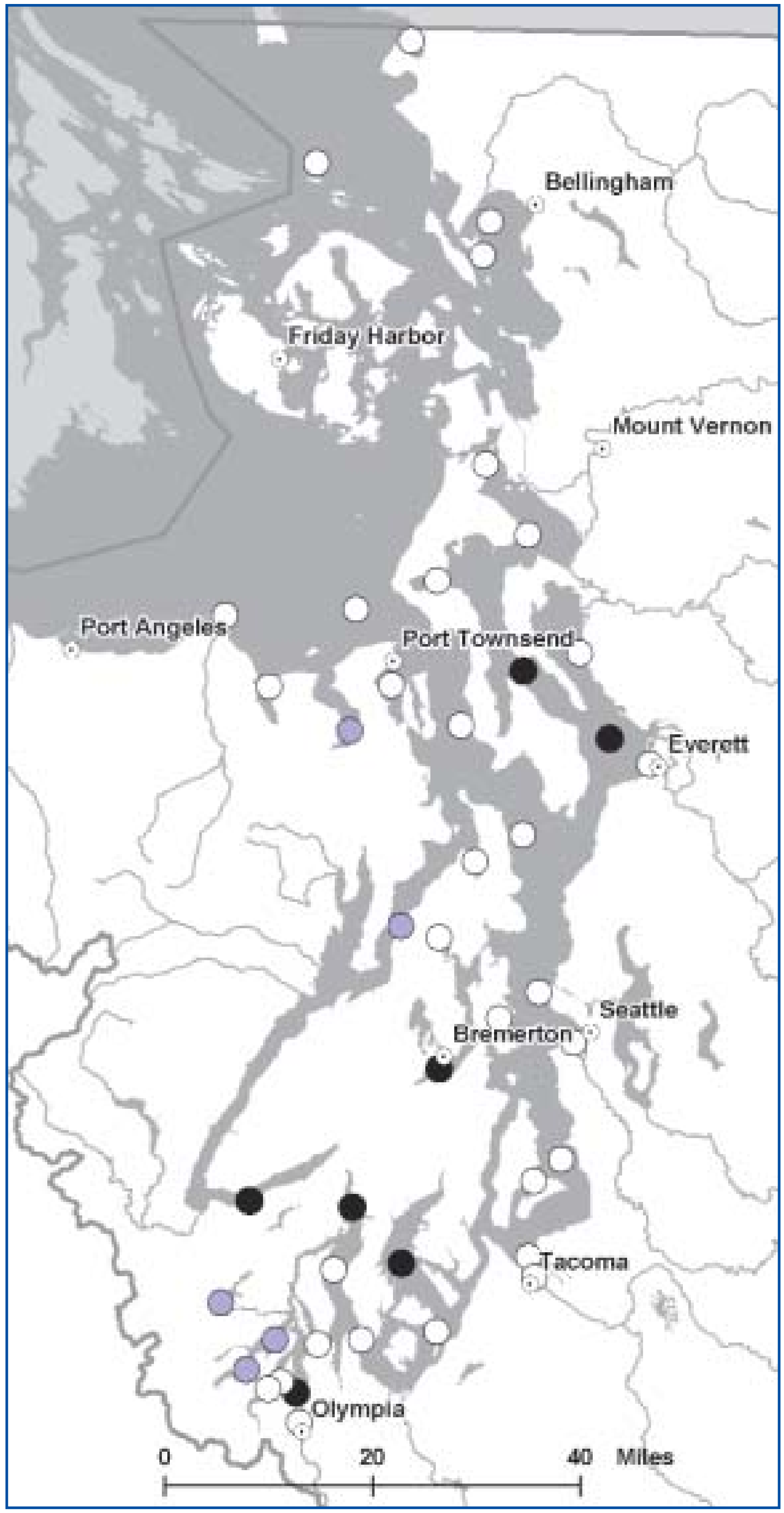
Figure 3-11 categorizes the monitoring stations by the number of months that DIN is not detectable over 1998 through 2000. Non-detectable levels indicate that nutrient availability may be limiting phytoplankton productivity and making the water body more susceptible to eutrophication if nutrients are added as a result of human activities. During the 1998 through 2000 time period, seven stations had no detectable DIN for five months or more. Two of the seven stations, Saratoga Passage and lower Hood Canal, had similar results in the 1996 to 97 data reported in the *2000 Puget Sound Update*. Data from three of the seven stations reflect increased nutrient limitation relative to 1996 through 1997: Possession Sound near Gedney Island, Sinclair Inlet and Budd Inlet. The remaining two stations of the seven were not sampled in 1996 and 1997.

Figure 3-12 shows the occurrence of elevated levels of ammonium as measured by the Department of Ecology in 1998 to 2000. High ammonium concentrations indicate the presence of an ammonia source and a potential water quality problem. Five stations had maximum ammonium concentrations greater than 10.0 mM (micro-molar). These were Bellingham Bay, Port Gardner, Sinclair Inlet and Budd Inlet. This

Figure 3-11. Dissolved inorganic nitrogen (DIN) at Puget Sound open-water monitoring stations, 1998-2000. Stations are ranked by the number of months in which no DIN is detectable. Nitrogen can be a significant limiting factor for primary production.

- ● not detectable 5 months or more
- ● not detectable 3-4 months
- ○ not detectable 0-2 months

Source: Washington State Department of Ecology



reflects increased ammonium concentrations at Sinclair Inlet and Possession Sound when compared to the results from 1996 through 1997. Data from the East Sound station at Orcas Island had high ammonium in 1996 through 1997 but this station was not sampled in 1998-2000. Stations with moderate levels of ammonium tended to be clustered in the south Sound area, while the northern Sound stations had low levels, except for the two urban water stations noted above.

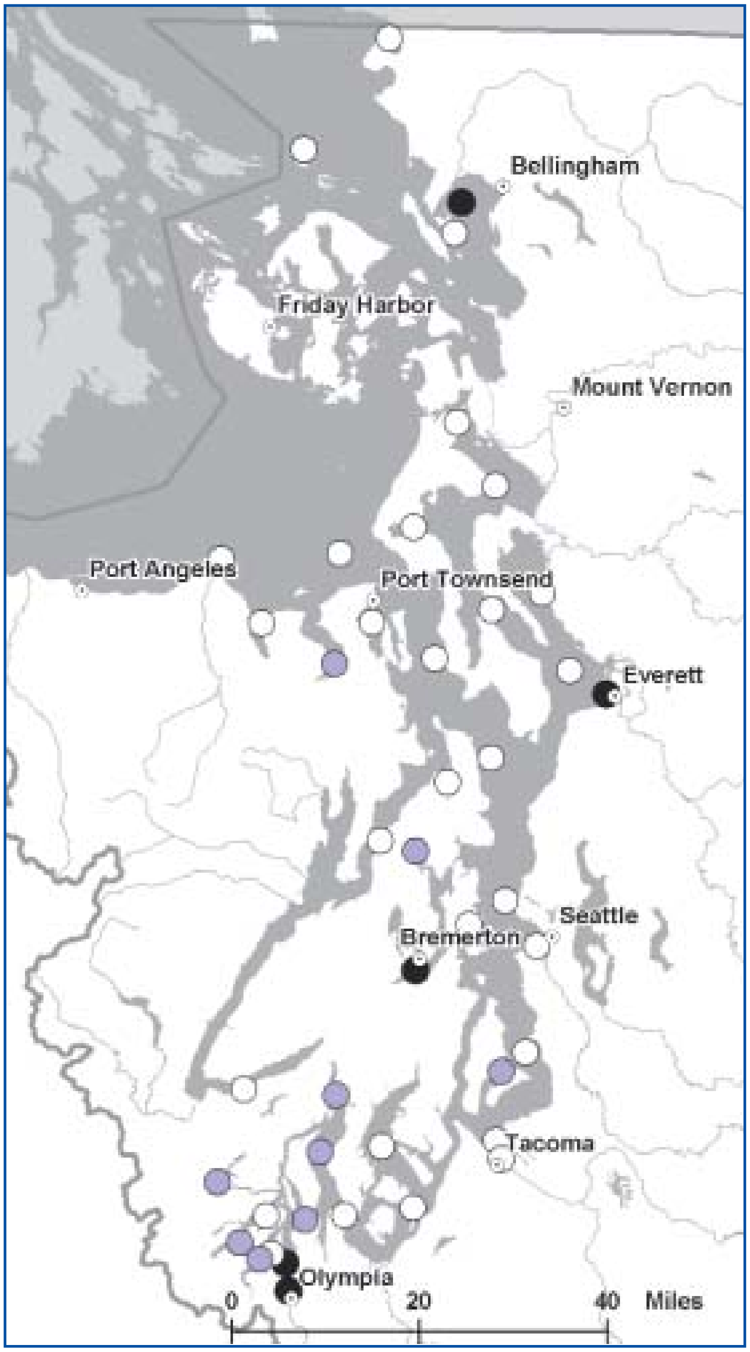
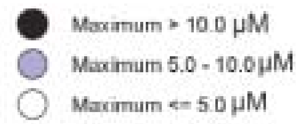


Figure 3-12. Maximum ammonium concentrations at the Department of Ecology's open water stations for 1998-2000. Threshold concentrations used to derive classes are in micro-molar (µM) units.



Source: Washington State Department of Ecology

Scientists from the Department of Ecology analyzed data from 1994 through 2000 to determine sensitivity to eutrophication (Table 3-2). This analysis incorporates data on DO and stratification intensity as well as DIN. The stratification and DO data are presented in more detail in Chapter 2. In a stratified water column, zones of depleted nutrients can develop in the surface, which can result in large blooms of algae if humans add nutrients. The rotting bloom can result in zones of low oxygen at depth, which can be deleterious to organisms. Thus, stratification has important implications for water quality because it regulates whether things will mix or stay in layers. Scientists identified three areas as having exceptional sensitivity to eutrophication due to a combination of low DO, low DIN and strong, persistent stratification. These areas are Budd Inlet, south Hood Canal and Penn Cove. Low DO measurements also provide evidence of direct water quality limitations that may be caused by eutrophication or may be natural.

Table 3-2. Washington State marine waters where eutrophication may be a concern based on data from 1994-2000.

DO=dissolved oxygen
DIN=dissolved inorganic nitrogen

SP = Strong and Persistent
SI = Strong and Intermittent
MI = Moderate and Intermittent
WI = Weak and Intermittent

Attributes of most concern for sensitivity to eutrophication are shown in blue.

Source: Washington State Department of Ecology

Station	DO	DIN	Stratification	Sensitivity to eutrophication
Budd Inlet	Very Low	Low	SP	exceptional
S. Hood Canal	Very Low	Low	SP	exceptional
Penn Cove	Very Low	Low	SP	exceptional
Possession Sound	Low	Moderate	SP	high
Bellingham Bay	Low	Low	SI	high
N. Hood Canal	Low	Low	SI	high
Saratoga Passage	Low	Moderate	SP	high
Sinclair Inlet	Low	Low	MI	high
Discovery Bay	Very Low	Moderate	MI	high
Carr Inlet	Low	Low	MI	high
upper Willapa Bay		Low	SI	high
Commencement Bay	Low		SP	high
Holmes Harbor	Low		SP	high
Skagit	Low		SP	high
Port Susan	Low		SP	high
Case Inlet	Low	Moderate	MI	high
Oakland Bay		Moderate	SI	moderate
Elliott Bay	Low		SI	moderate
Strait of Georgia	Low		SI	moderate
Drayton Harbor		Low	MI	moderate
outer Willapa Bay		Low	MI-WI	moderate
Totten Inlet		Moderate	MI	moderate
Eld Inlet		Moderate	MI	moderate
Quartermaster Hrbr	Low		MI	moderate
East Sound	Low		MI	moderate
Dungeness	Low		MI	moderate
Port Gamble	Low		MI	moderate
Sequim Bay	Low		MI-WI	moderate
Port Townsend	Low		MI	moderate
Grays Harbor			SP-MI	low
Dyes Inlet		Moderate	WI	low
Port Orchard			MI	low
West Point			MI	low
Burley-Minter			MI	low

Acting on the Findings

This chapter presented recent findings on levels of pathogens and nutrients in fresh and marine waters within the Puget Sound basin. This is clearly a critical component of the monitoring effort in Puget Sound because of the implications for human health and the potential effects on an important segment of the local economy that is adversely affected by high pathogen levels.

Several recommendations can be made based on the studies presented in this chapter:

- Intensive and coordinated local efforts can reduce fecal pollution problems as evidenced by successes in the Nooksack basin as well as seen in previous results for Eld Inlet and Oakland Bay presented in the *2000 Puget Sound Update.*

- Such efforts should be initiated at all areas where the state Department of Health's analysis indicates worsening trends, especially those areas where currently open shellfish harvest areas would be threatened with downgrades if the trend were to continue. These include Henderson Inlet, Dungeness Bay, south Skagit Bay and others.
- Monitoring should, wherever possible, adopt an interdisciplinary approach that integrates sampling of pathogens and nutrients with physical parameters of the receiving waterbody and the nature of the sources. Areas of Puget Sound that are sensitive to nutrient-related water quality degradation should be investigated further to characterize nutrient loading and cycling.
- Decisions about the discharge of nutrients to Puget Sound from point and nonpoint sources should incorporate an understanding of the local marine area's sensitivity to nutrient-related water quality degradation. Areas of Puget Sound shown to be sensitive to eutrophication should be managed accordingly.